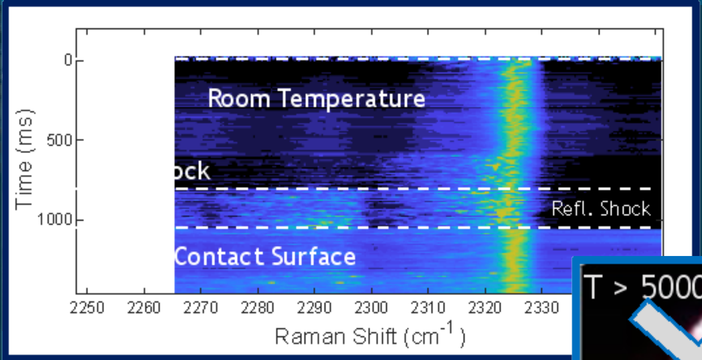
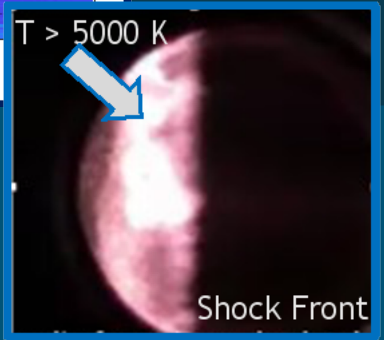
SAND2021-15096C

Sandia National Laboratories

Burst-mode coherent anti-Stokes Raman scattering thermometry in the Sandia free-piston shock tube





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Sandia National Laboratories, Albuquerque, NM 87185

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Daniel Lauriola[#], Jason Leicht*, Terry Meyer[#], Mikhail Slipchenko[*#]*
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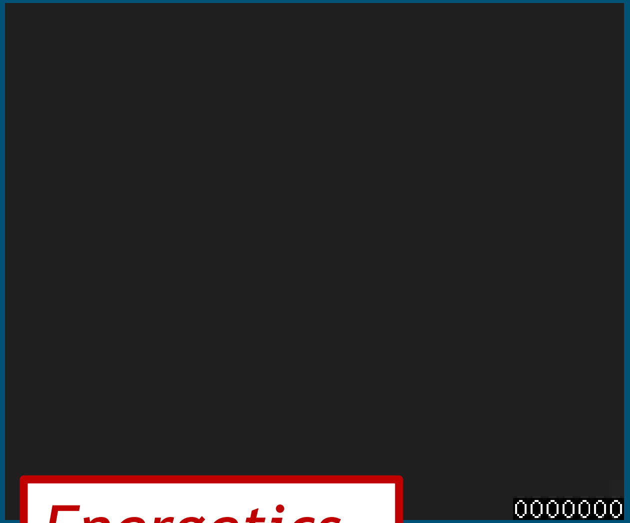
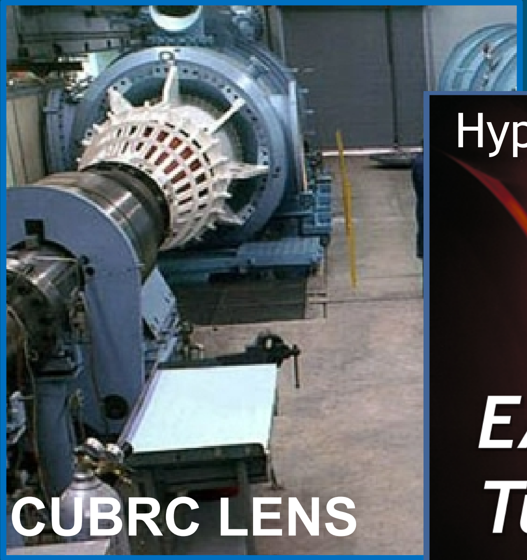
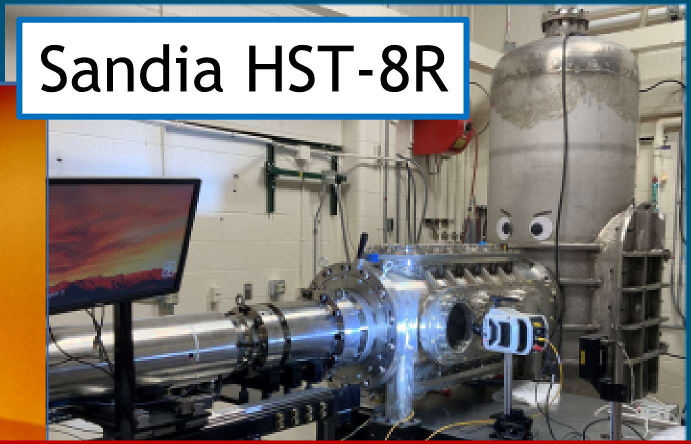
Motivation: Hypersonics and energetic materials are receiving renewed interest



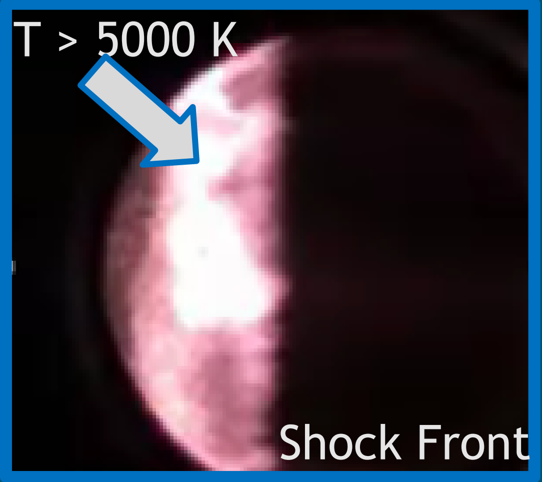
Energetics





Impulsively driven, dynamic experiments

Very high temperature systems: T = 4000--6000K or more!



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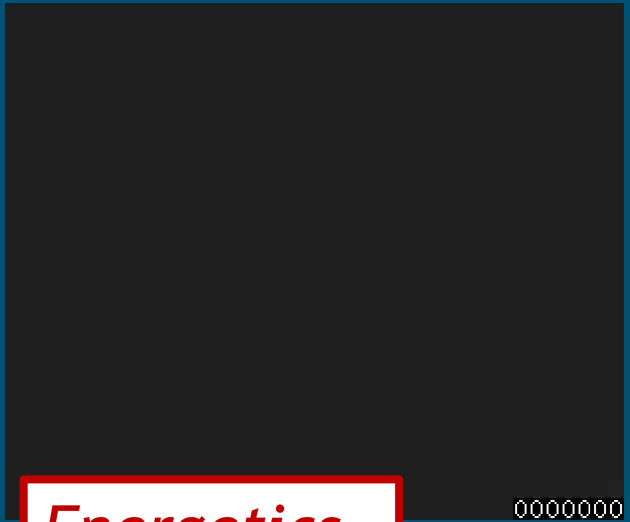

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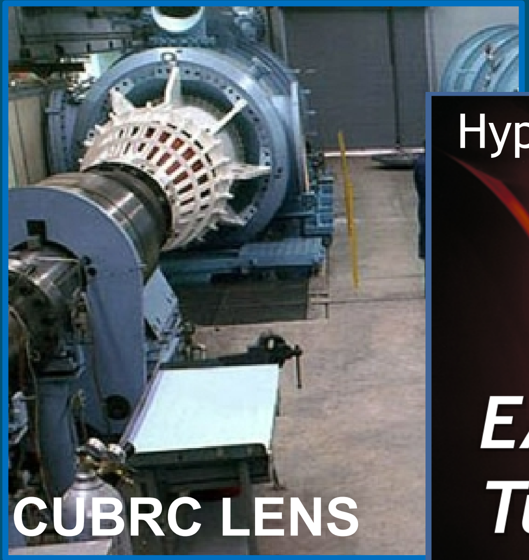

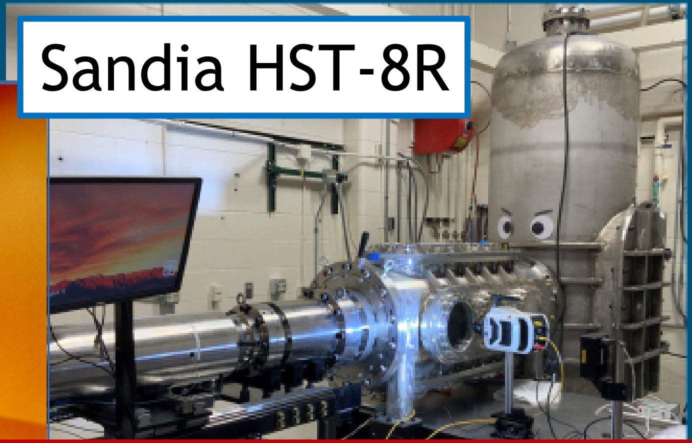

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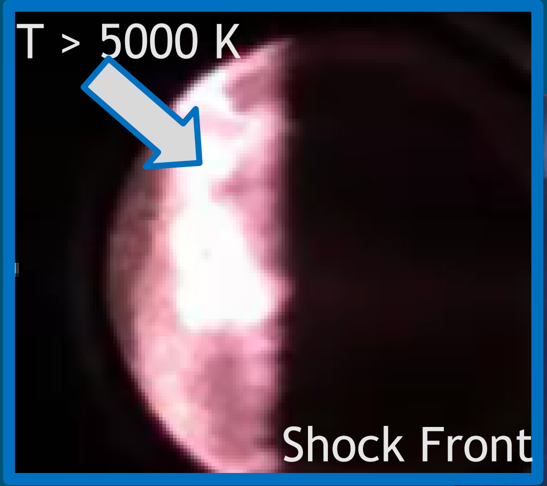
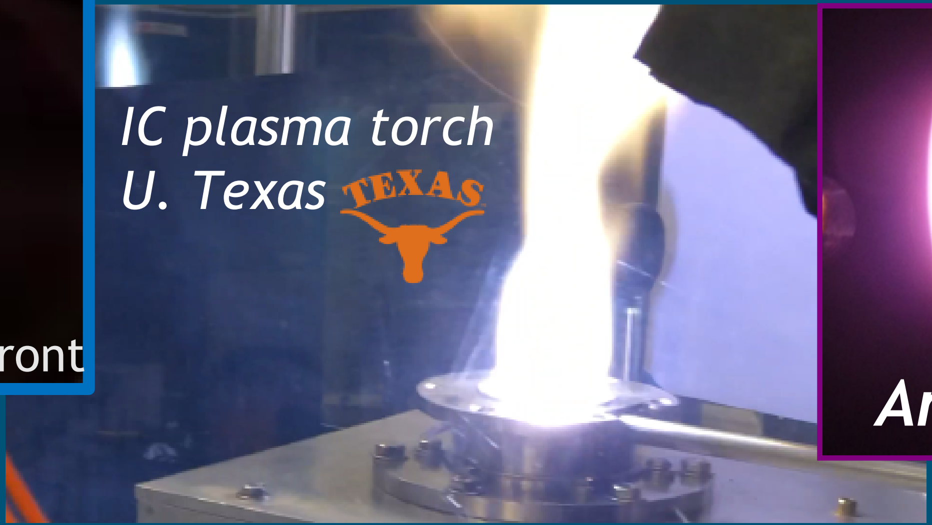
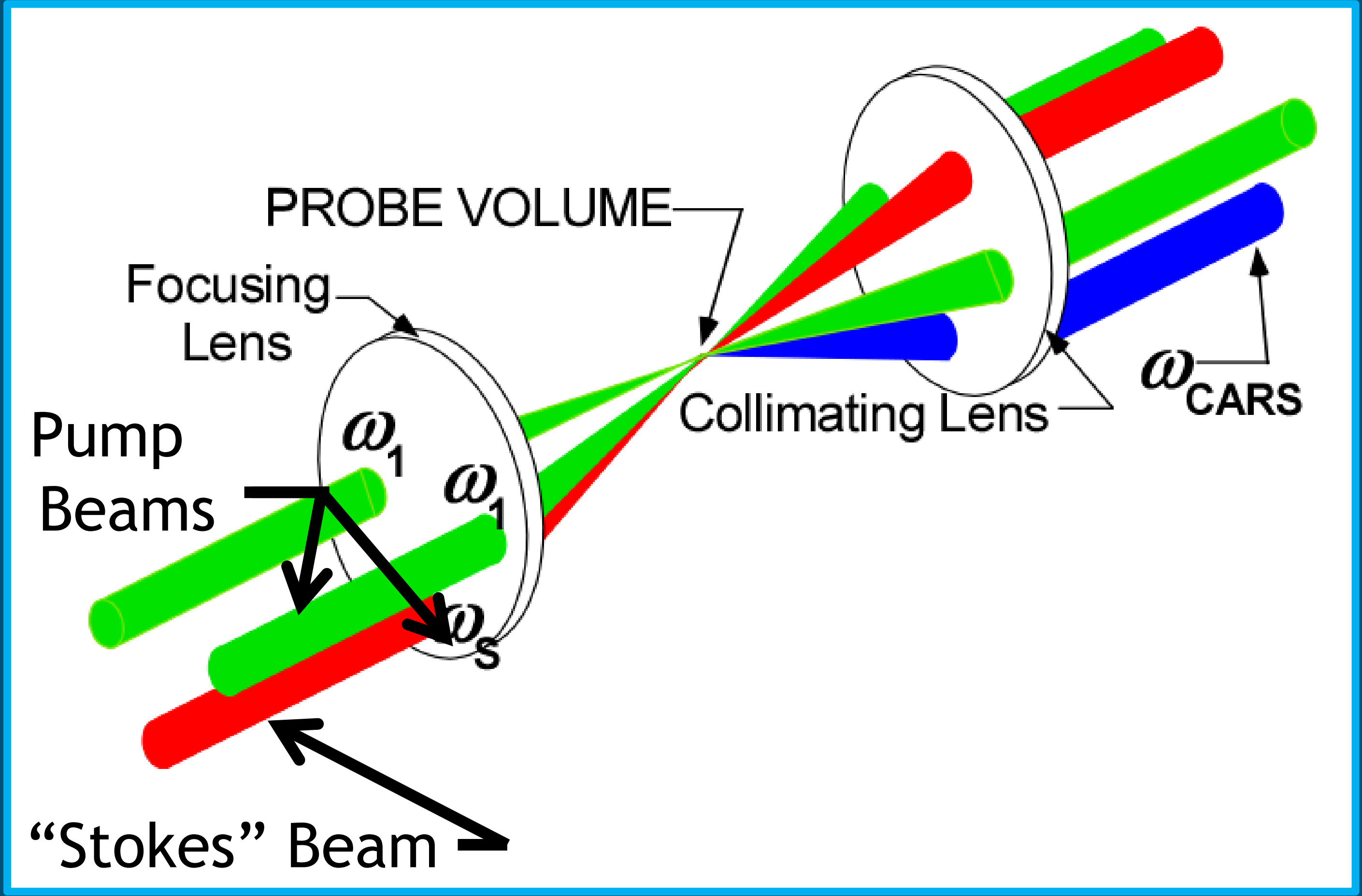




Coherent anti-Stokes Raman scattering (CARS)



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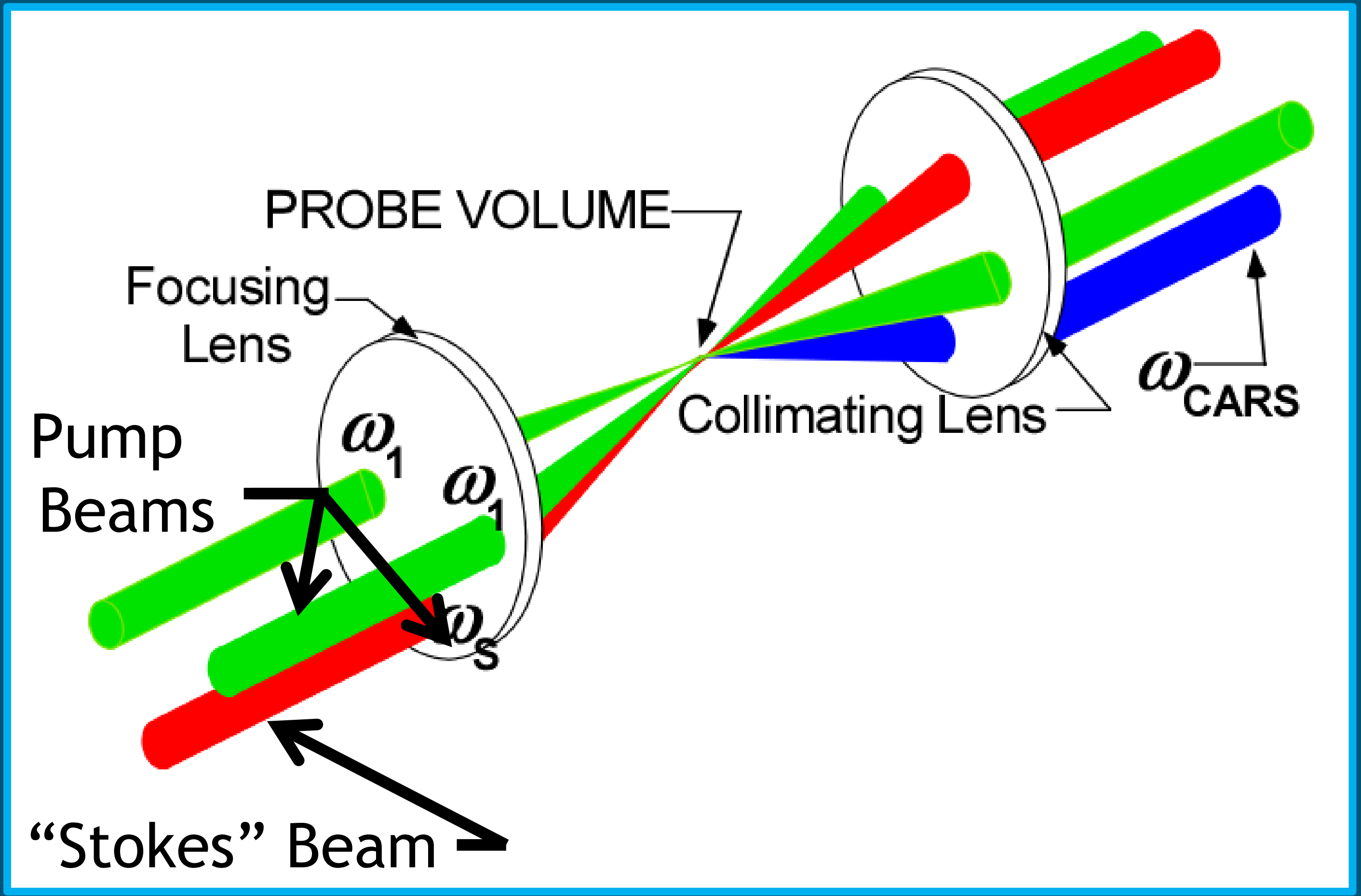
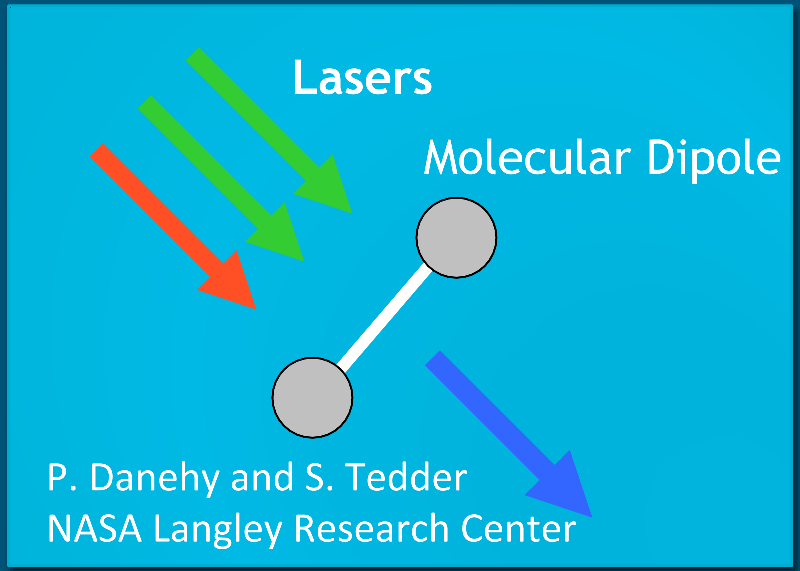
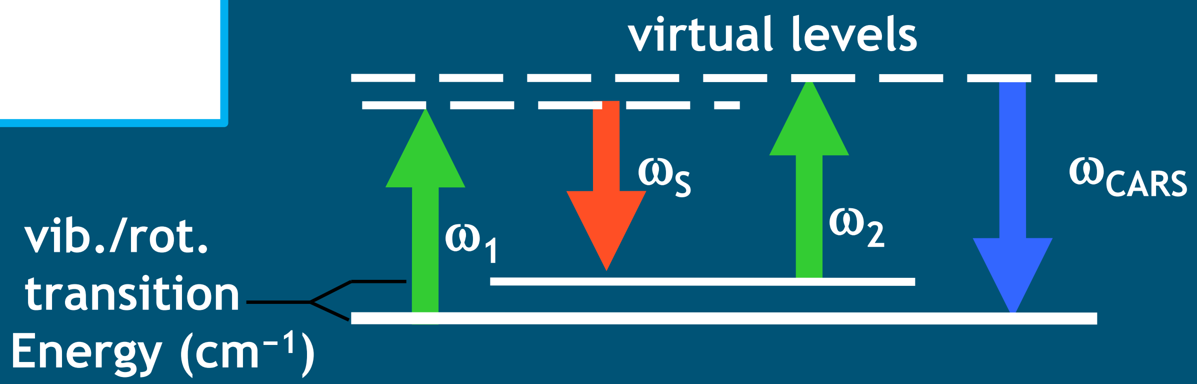




Coherent Anti-Stokes Raman



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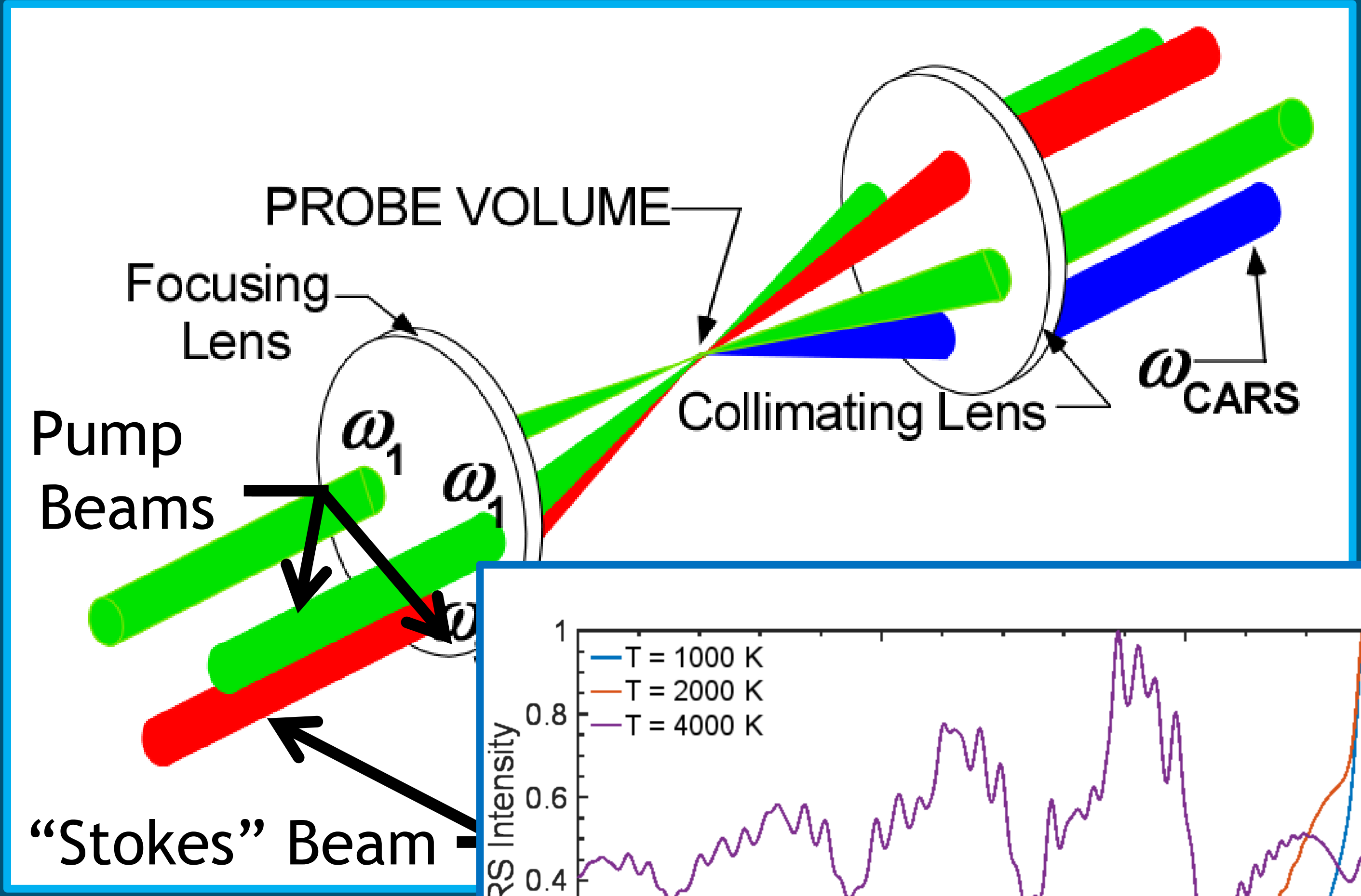
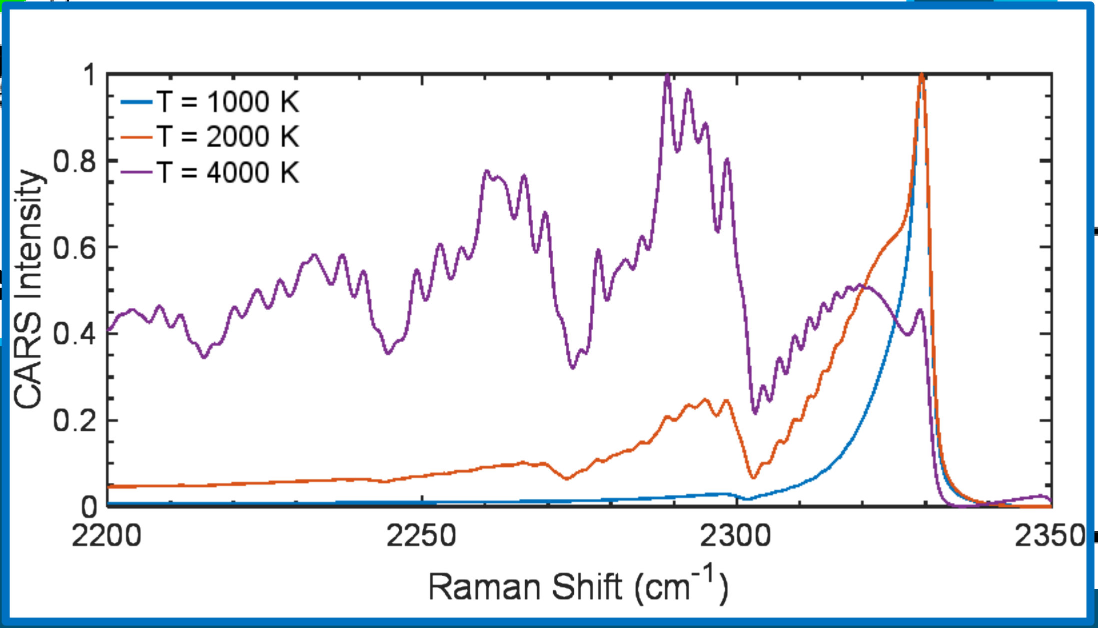
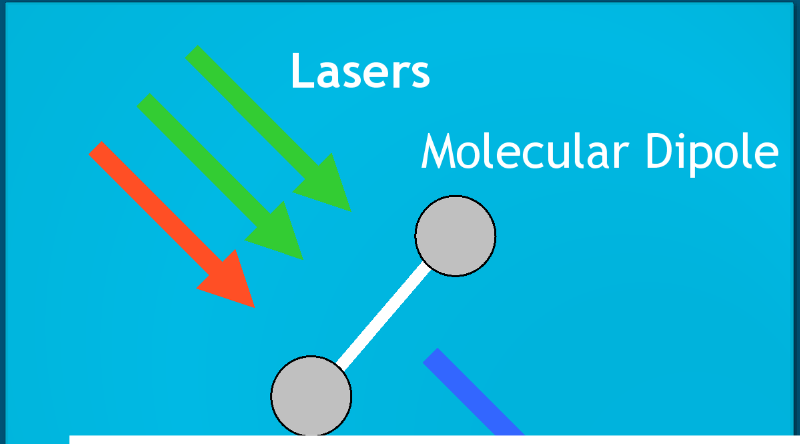
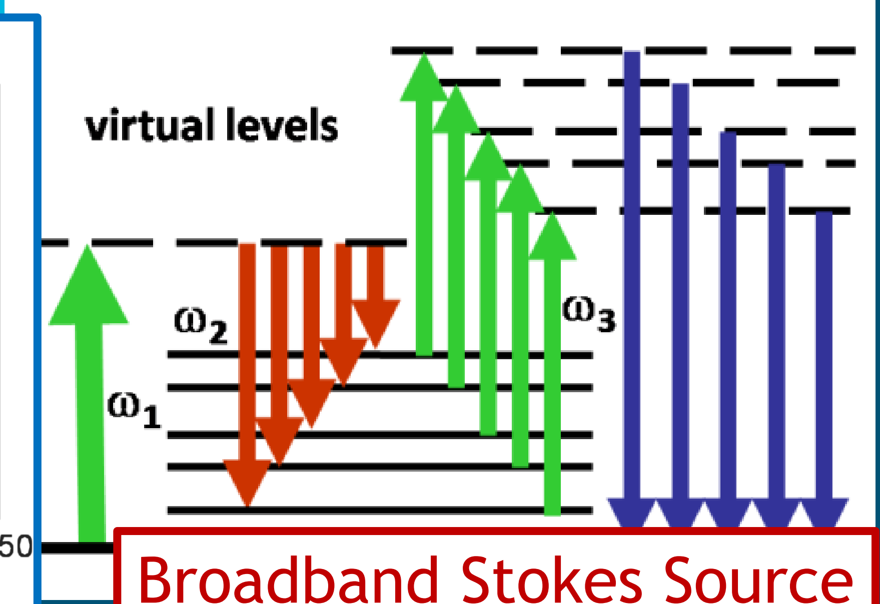




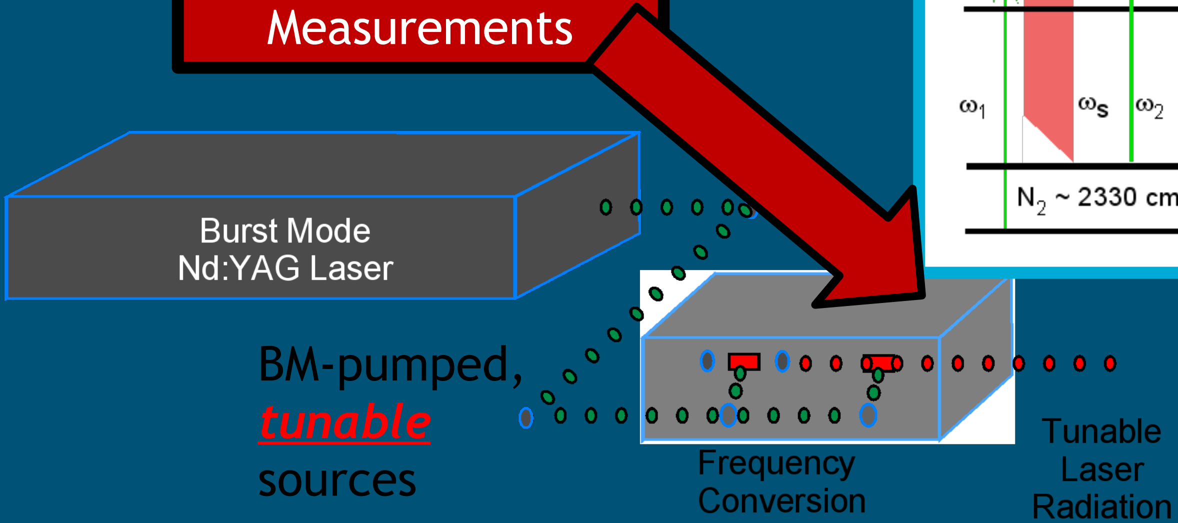




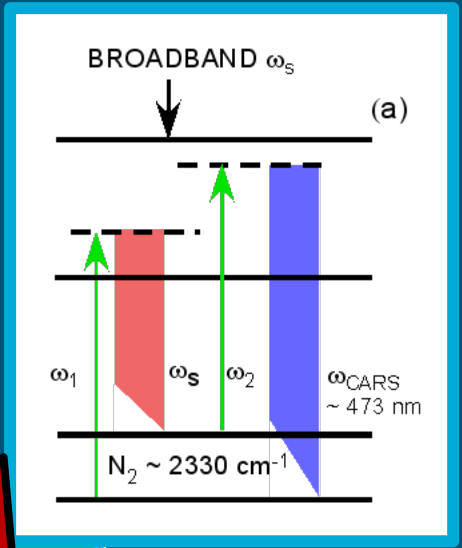
Broadband Stokes Source for single-shot detection

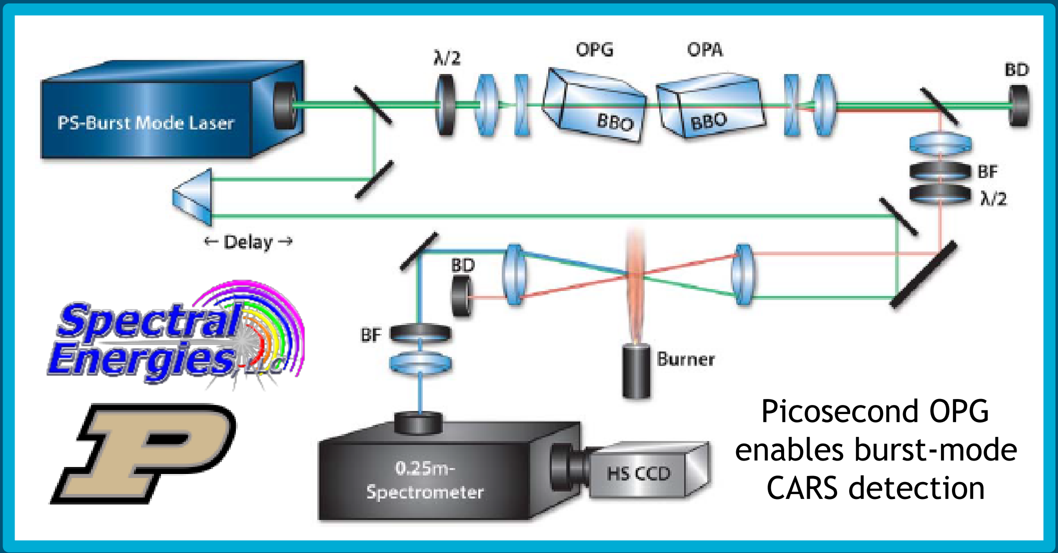
Pulse-Burst CARS: Sandia/SE/Purdue Collaboration

Broadband Source is Key Technical Barrier for High-Speed Measurements

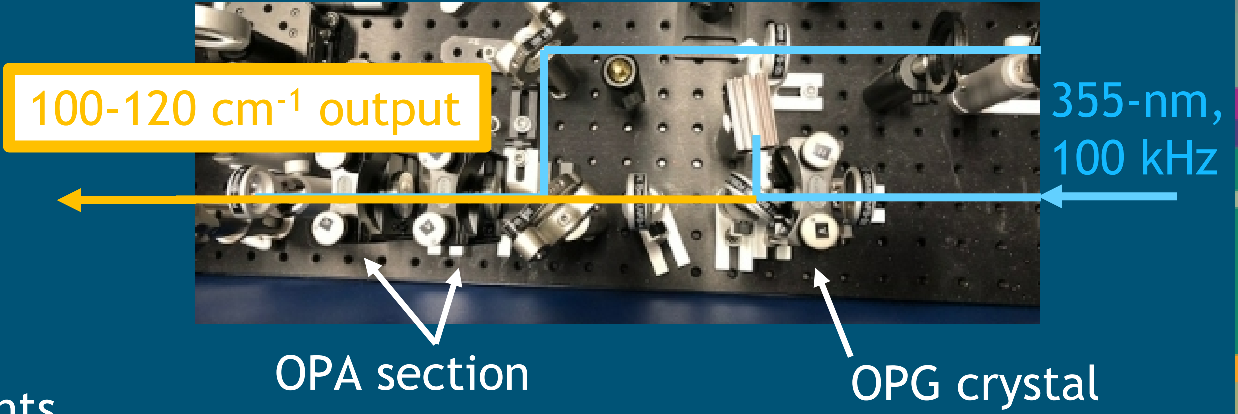


BM-pumped, *tunable* sources



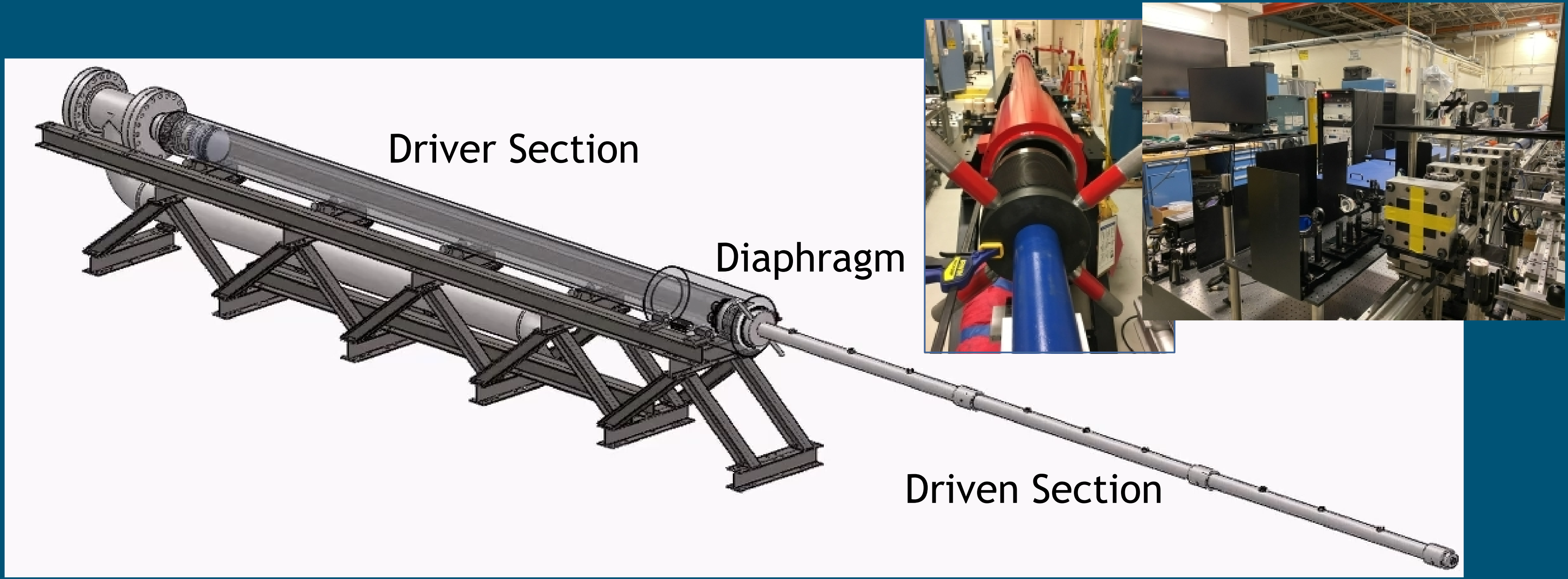


Picosecond OPG/OPA for 100-kHz broadband generation (Roy et al., 2015)

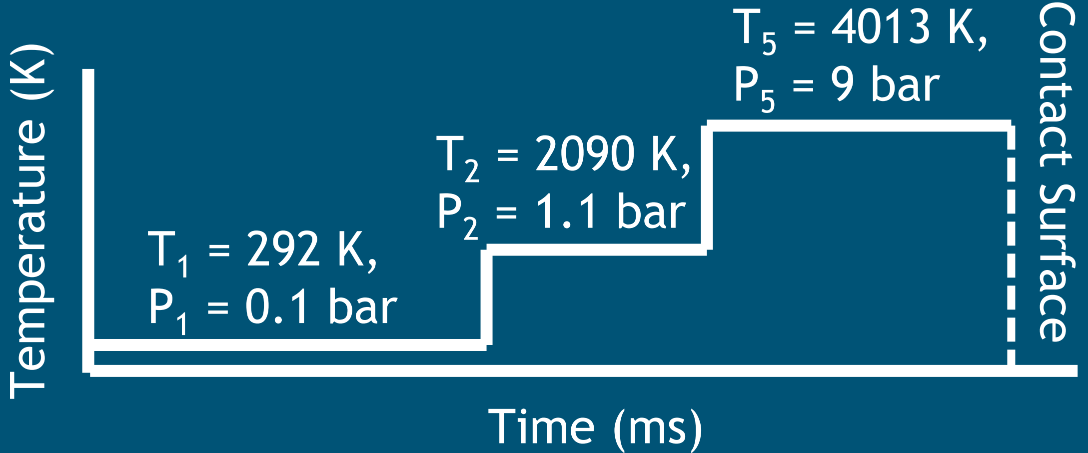


- Picosecond burst-mode laser from SE enables efficient broadband OPG and subsequent amplification
- Technology originally demonstrated in H_2/air and N_2/air flames by SE/Purdue team
- Bandwidths and 1-2 mJ pulse energies sufficient for N_2 CARS!
- Delivered to Sandia for shock tube facility measurements

100-kHz Pulse-Burst CARS in the Sandia Free-Piston Shock Tube



- 100-kHz N_2 Vibrational CARS using picosecond pulse-burst laser technology
- High-temperature/high-pressure conditions present challenging measurement environment



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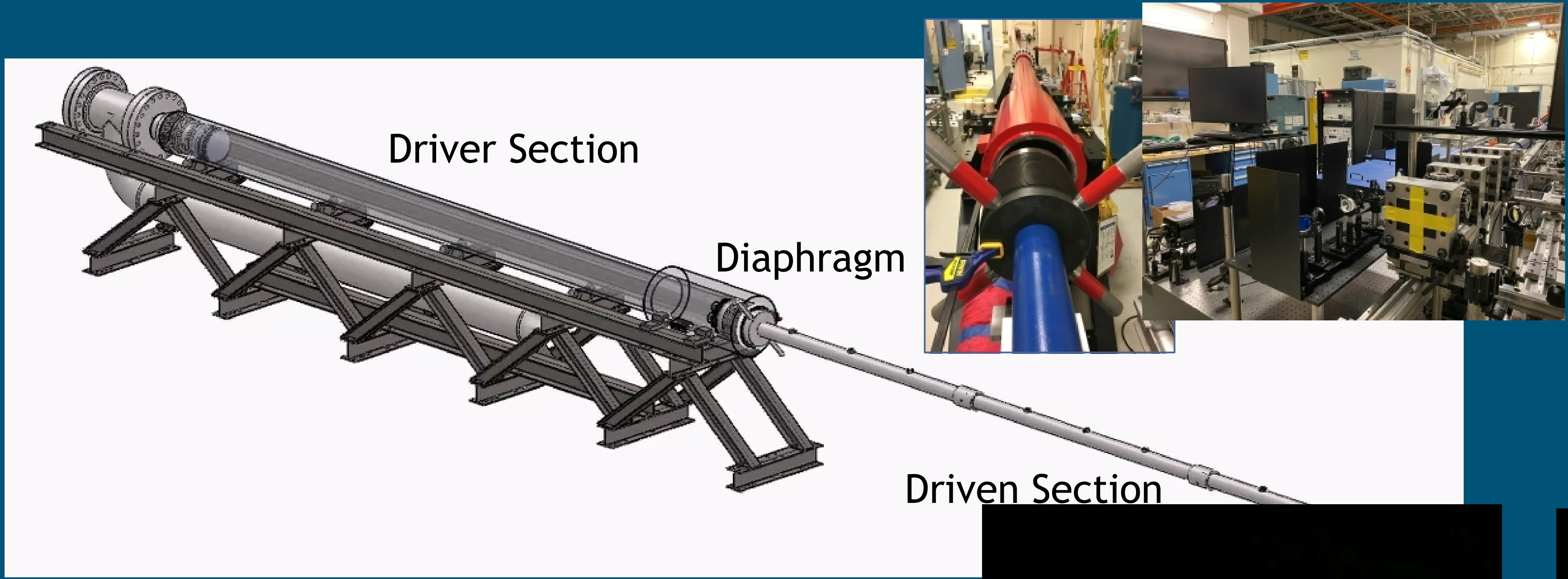

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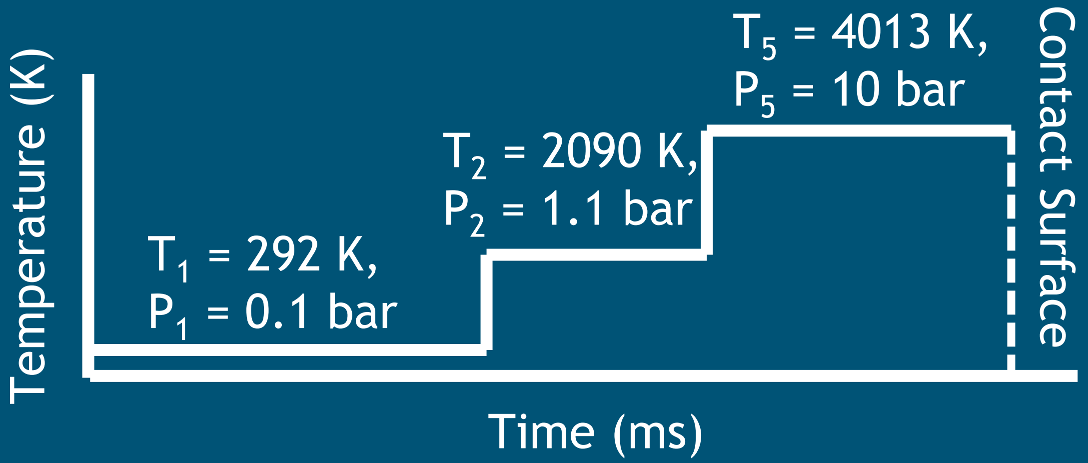

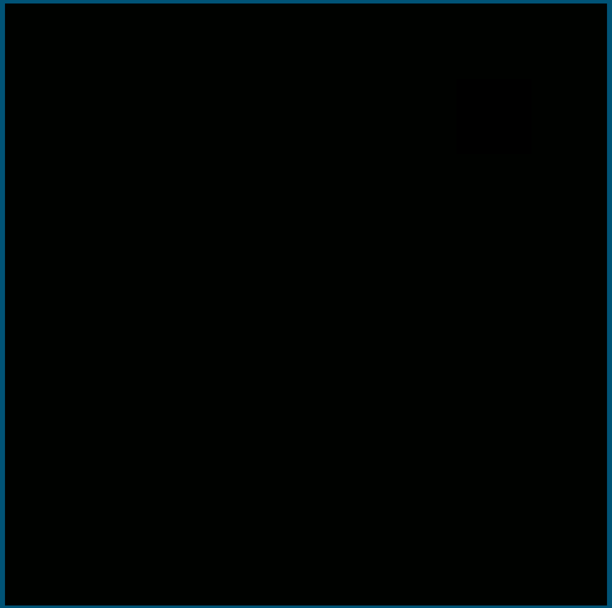

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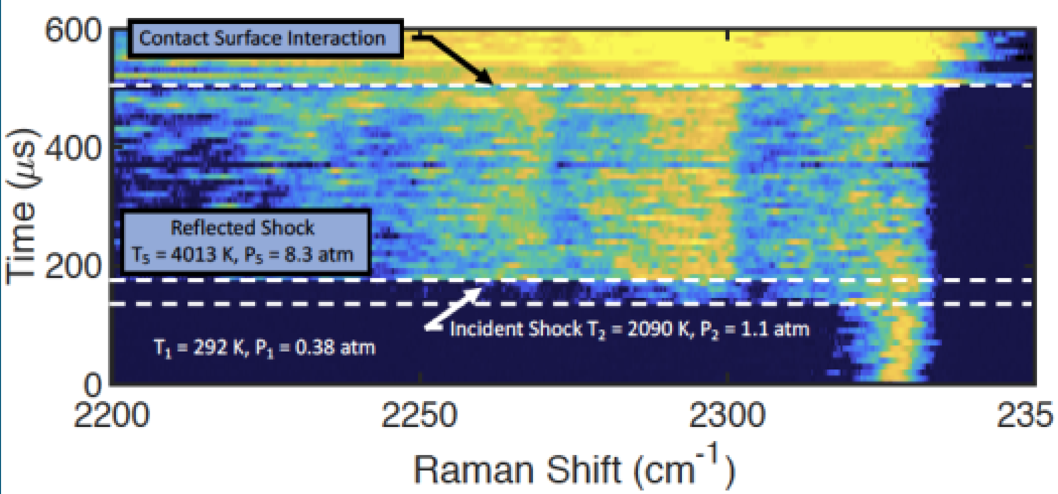
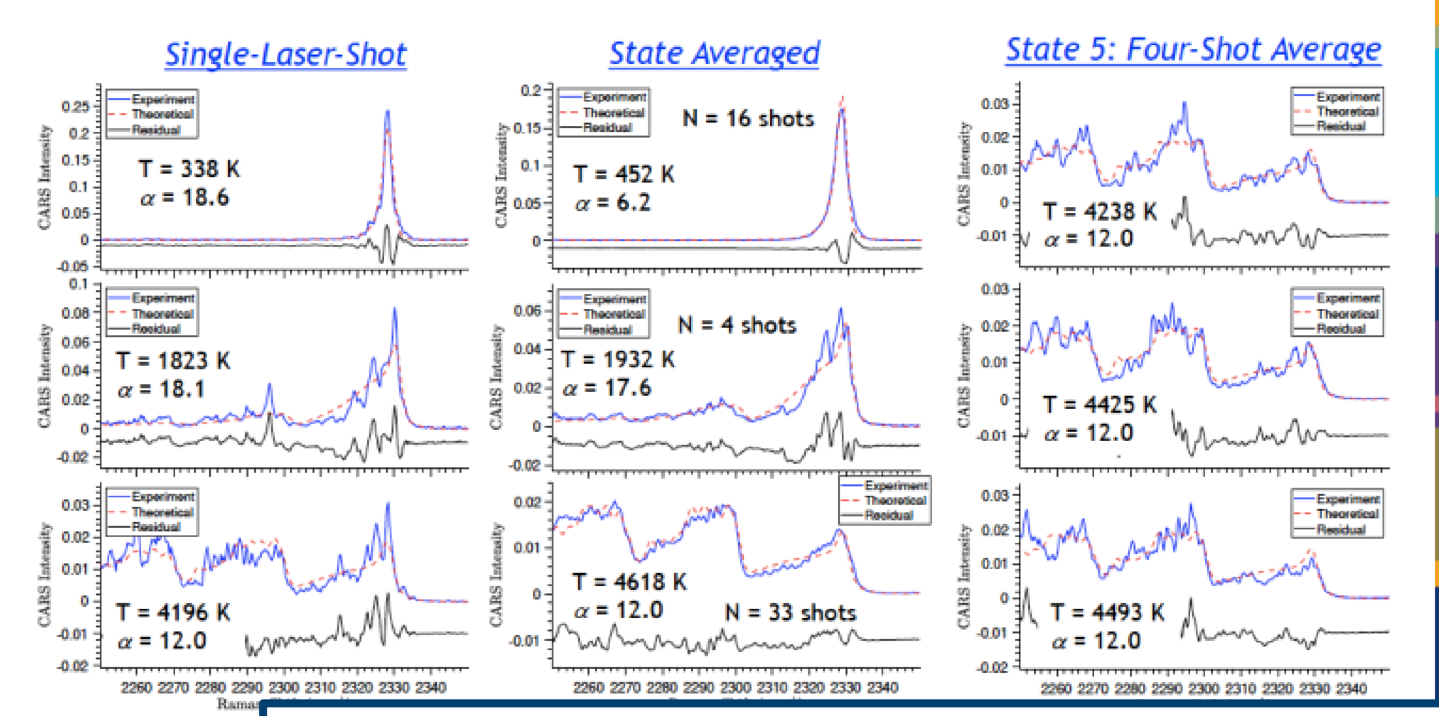
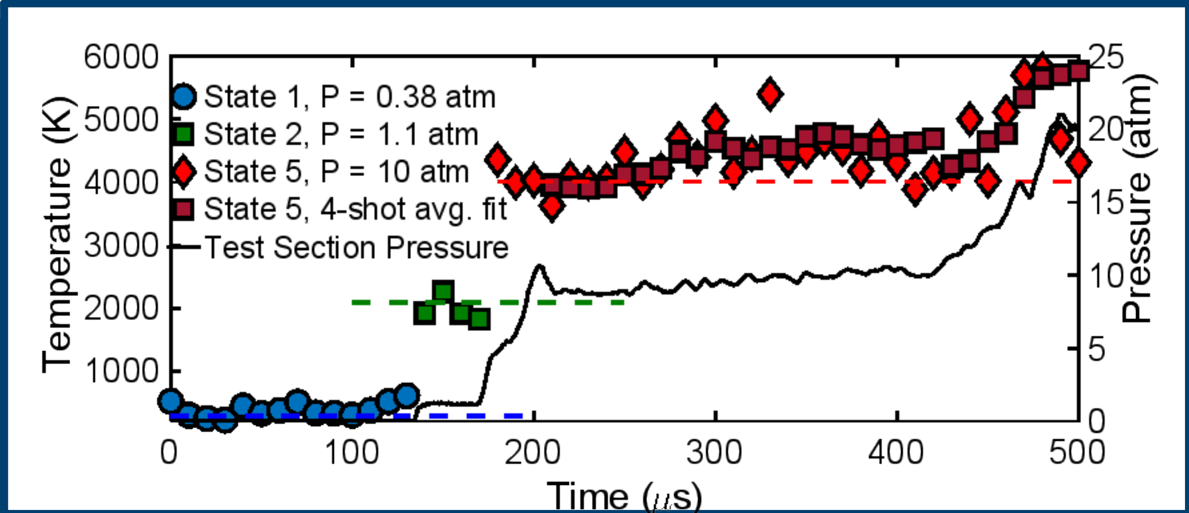




Next Steps

- Develop appropriate models to fit picosecond CARS spectra for temperature
- Implement reference signal leg to monitor and correct the effects of Stokes pulse noise spectrum
- Insert spatial filter to minimize shock-tube emission background
- Higher temperature shots (T2 = 3000 K, T5 = 5000 K)
- Development of *nanosecond* pulse-burst CARS

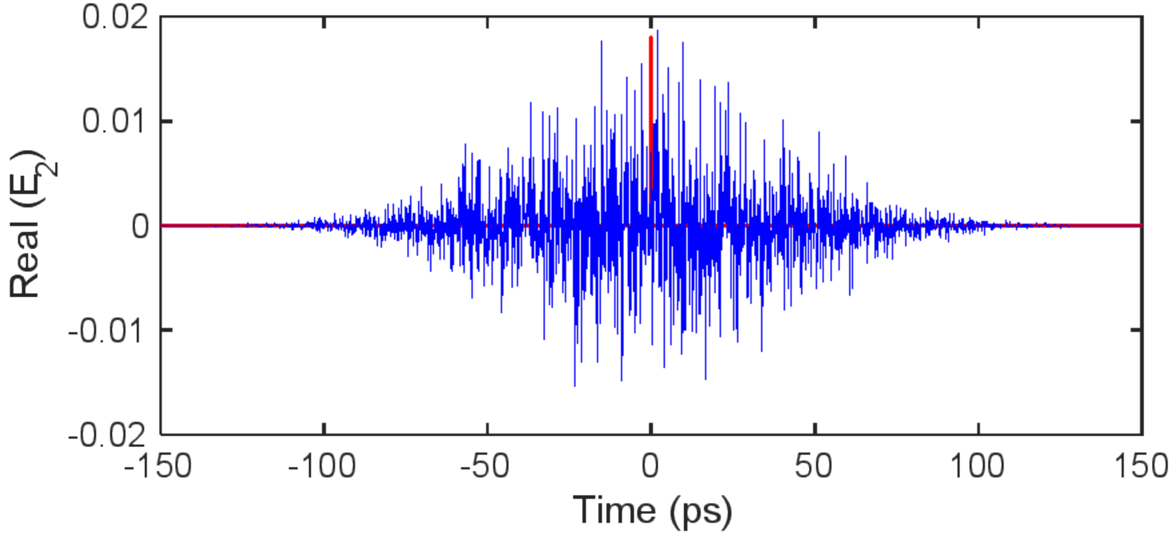


Picosecond CARS modeling and inherent single-shot noise

Dominant source of CARS noise is the quality of the broadband pulse

Time-Bandwidth Product

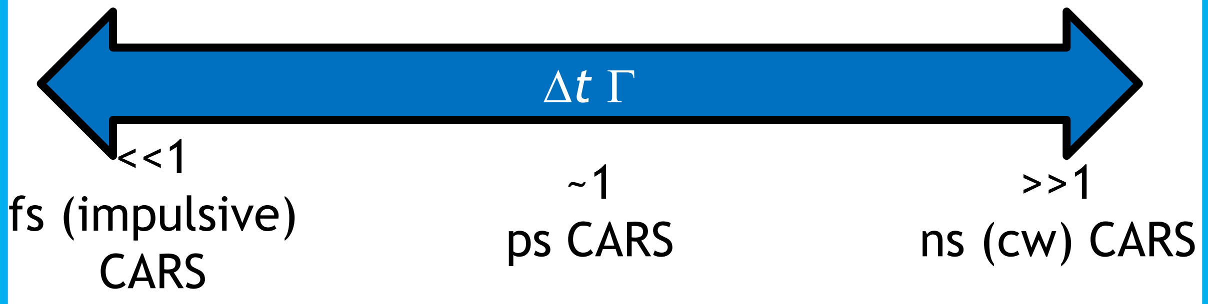
$$\Delta t\left[\mathrm{ps}\right]\Delta\omega\left[\mathrm{cm}^{-1}\right] \geq 14.67$$



- To achieve sufficient bandwidth for CARS, pulse must exhibit ~150-fs features – inherently noisy!

- Δt ~ 50-100 ps ~ $1/\Gamma$ → very little averaging in the Raman process

Picosecond CARS lies between cw and impulsive limits



- A rigorous time-dependent approach is needed to calculate the *expected value* of the ps CARS signal

$$\left\langle S_4\left(\omega;\tau_{12},\tau_{23}\right)\right\rangle = \int_{-\infty}^{\infty} I_1\left(t_1\right) I_2\left(t_1-\tau_{12}\right) G\left(\omega;\tau_{23}-t_1\right) dt_1$$

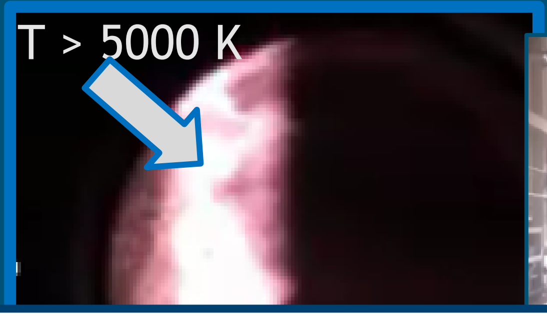
Weighted by time-dependent pump/Stokes Intensities

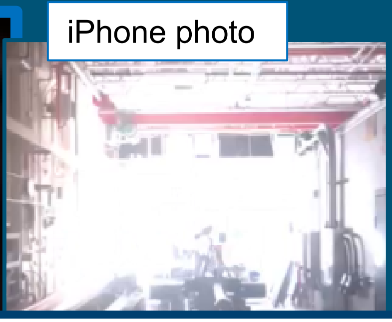
Impulsive CARS spectrum, *G*

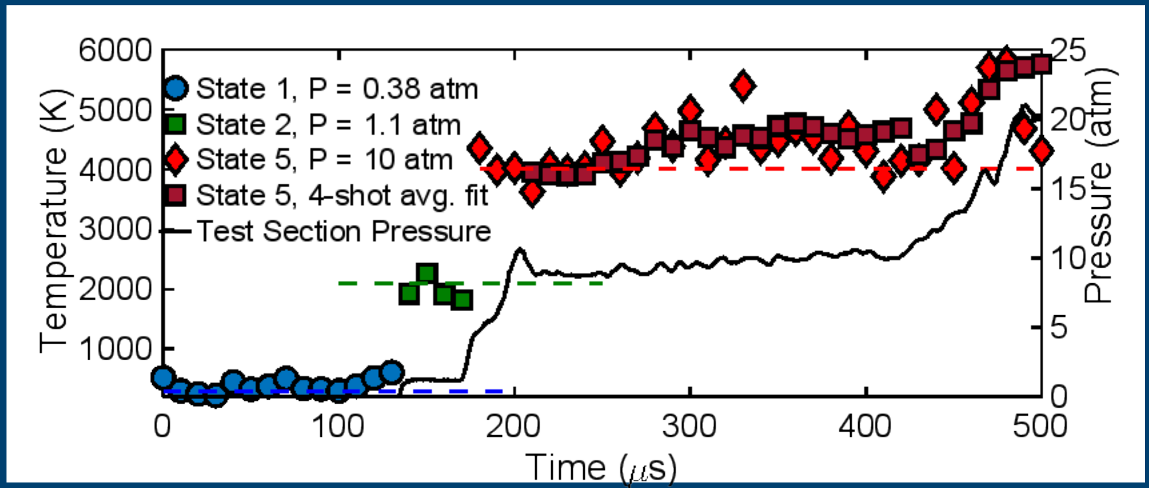
- Solution is an *incoherent sum*
- *Uncorrelated, impulsive CARS processes*

Summary and Conclusion

- Picosecond pulse-burst lasers have enable CARS diagnostics at 100-kHz rates
  - Roy et al. 2015; Lauriola et al. 2021
- We have applied this picosecond innovation for N_2 CARS thermometry in the Sandia free-piston shock tube
  - Extremely high temperatures, up to T = 5000 K
  - Pressures to ~ 10 bar
  - Significant background luminosity
- N_2 CARS temperatures in good agreement with values from equilibrium calculations







- Picosecond CARS is an enabling technology for high-speed thermometry
  - Single-shot Stokes source corrections (Lauriola et al., 2021)
  - Nanosecond burst-mode NOPO source (Jans, SciTech, 2022)